Prediction of the solar radiation using RBF Neural Networks and ground-to-sky images

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EXTENDED ABSTRACT

In this study, Artificial Neural Networks are applied to multi-step long term solar radiation prediction. The networks are trained as one-step-ahead predictors and iterated over time to obtain multi-step longer term predictions. *Auto-regressive* and *Auto-regressive with exogenous inputs* solar radiation models are compared, considering cloudiness indices as inputs in the latter case. These indices are obtained through pixel classification of ground-to-sky images. The input-output structure of the neural network models is selected using evolutionary computation methods.

Global solar radiation (SR) influences the majority of living beings in many different ways. In the particular case of interest it affects greatly the energy consumption patterns of society. Having reasonably good predictions of SR evolution within a given future horizon is a key factor for many practical applications where the minimization of energy consumption constitutes an objective. A review of applications in renewable energy systems based on SR forecasting can be found in [1]. Many environmental control strategies in buildings are expressed as optimization problems where at least two goals need to be met: the minimization of energy consumption and the optimization of some criteria inherent to the activity in the building or its occupants. Consider, for example, heating ventilation and air conditioner (HVAC) systems in building compartments [2]: one wants maximize the level of thermal comfort with minimal energy consumption. In [3] it is shown that the temperature estimation of a particular compartment depends mostly on SR. Another example are production greenhouses: the grower wants to achieve good temperature and humidity regulation at the smallest energy costs possible while maximizing crop growth and production. These are greatly dependent on temperature and SR integrals. In both examples the influence of SR on the processes is twofold: it affects the controlled variables and the process being optimized.

Previous work, showed that the predicted SR time series obtained, have a very smooth behaviour capturing the series trend within the prediction horizon. However, in cloudy days the models fail to capture the dynamics caused by cloudiness, partially because the models use only measured past SR values as inputs. In order to obtain more accurate SR predictions, information on cloudiness should be fed to the models. In this work cloudiness information is incorporated in the Artificial Neural Network (ANN) SR model with the aim of obtaining better predictions in the presence of cloud activity. *Non-linear Auto-regressive* (NAR) and *Non-linear Auto-regressive with Exogenous inputs* (NARX) models are compared. In the later case a cloudiness index is the only exogenous input. The comparison will give insight about the usefulness of cloudiness indices to the SR models.

The models employed in the NAR and NARX are based on the Radial Basis Function Neural Networks (RBFNN). The feed-forward RBFNN was chosen for its structural simplicity, the *universal approximation property* [4], the nonlinear nature of the time series to be modelled, and also due to its tolerance to imprecision and noise. The training process employed can be found in detail in [5], [6]. The model structure, witch are, the lagged inputs variables terms and the number of neurons are achivied using the method described in [7], [8], [9], [10] and is based in an evolutionary computing approach, or, in a more concrete matter, the *Multi-Objective Genetic Algorithm* (MOGA) [11], [12].

In order to train the RBFNN models, a data set are required. Real data were obtained from a acquisition system installed on the roof of the Faculty of Sciences and Technology building

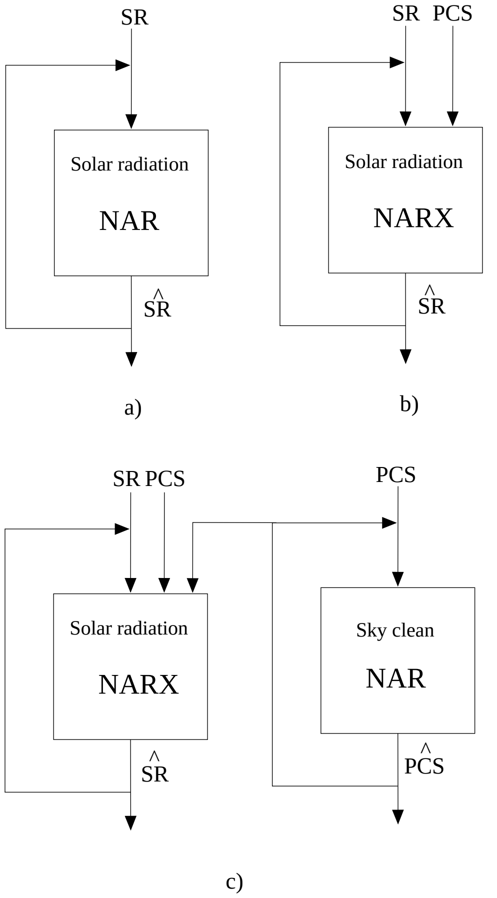

Fig. 1. NAR AND NARX MODELS

of the University of Algarve, Portugal. It consists of a solar radiation sensor, measuring the global solar radiation in $Watts \times m^{-2}$, and a Total Sky Imager (TSI), that takes pictures of the sky using a CCD camera. The data is stored in a local computer with a period of 1 minute. Once collected, the sky images are processed in order to obtain the cloudiness indices (as percentages). This process consists a pixel-by-pixel classification, involving also a RBFNN, witch in this particular process behaves as a RBFNN classifier.

For prediction, three different models were used. The first is a NAR solar radiation model, illustrated in Figure 1 a). This model only requires the SR past value for one-step-ahead (OSA) prediction, while for the multi-step predictions, requires that the predicted values ($\hat{SR}$) need to be feed in the inputs of the NAR. Secondly a NARX model as depicted in Figure 1 b), incorporates PCS values as exogenous inputs. Finally, as this model requires PCS predicted values in order to perform long term multi-step predictions, a third NAR model is considered for PCS as shown in Figure 1 c).

For each NAR and NARX model presented in Figures 1, one MOGA run was computed (please consult [7], [8], [9], [10] for a more detailed explanation of the method), and chosen an optimal model structure from a candidate set returned by the MOGA. This candidate set obtained are RBFNN models that meet pre-specified objectives parameters. In general, performance and model complexity objectives were specified.

The results of the experimental setup demonstrated that the use of the cloudiness indices can be beneficial for solar radiation prediction. However, in terms of practical applicability, preliminary results are not completely satisfactory. The error introduced by the required cloudiness index estimated values, limits the accuracy of the NARX solar radiation predictions, in such way that the results are comparable to those obtained by NAR solar radiation models. In order to overcome this limitation, the cloudiness index predictive models need improvement in terms of accuracy and dynamics. This can be obtained through better pixel classification of the sky images, which is ongoing research. Future work will address the use of an alternative radial basis function (multi-quadric) which in recent tests showed improvements in the cloudiness indices models.

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